Effects of creatine supplementation on body composition, strength, and sprint performance

KREIDER, RICHARD B.; FERREIRA, MARIA; WILSON, MICHAEL; GRINDSTAFF, PAMELA; PLISK, STEVEN; REINARDY, JEFF; CANTLER, EDWARD; ALMADA, A. L.

Author Information

Exercise & Sport Sciences Laboratory, Department of Human Movement Sciences & Education and the Department of Intercollegiate Athletics, The University of Memphis, Memphis, TN 38152; and Experimental & Applied Sciences, Inc., Golden, CO 80401

Submitted for publication February 1997.

Accepted for publication September 1997.

Abstract

Purpose: To determine the effects of 28 d of creatine supplementation during training on body composition, strength, sprint performance, and hematological profiles.

Methods: In a double-blind and randomized manner, 25 NCAA division IA football players were matched-paired and assigned to supplement their diet for 28 d during resistance/agility training (8 h·wk⁻¹) with a Phosphagen HP (Experimental and Applied Sciences, Golden, CO) placebo (P) containing 99 g·d⁻¹ of glucose, 3 g·d⁻¹ of taurine, 1.1 g·d⁻¹ of disodium phosphate, and 1.2 g·d⁻¹ of potassium phosphate (P) or Phosphagen HP containing the P with 15.75 g·d⁻¹ of HPCE pure creatine monohydrate (HP). Before and after supplementation, fasting blood samples were
obtained; total body weight, total body water, and body composition were determined; subjects performed a maximal repetition test on the isotonic bench press, squat, and power clean; and subjects performed a cycle ergometer sprint test (12 × 6-s sprints with 30-s rest recovery).

**Results:** Hematological parameters remained within normal clinical limits for active individuals with no side effects reported. Total body weight significantly increased ($P < 0.05$) in the HP group (P 0.85 ± 2.2; HP 2.42 ± 1.4 kg) while no differences were observed in the percentage of total body water. DEXA scanned body mass (P 0.77 ± 1.8; HP 2.22± 1.5 kg) and fat/bone-free mass (P 1.33 ± 1.1; HP 2.43 ± 1.4 kg) were significantly increased in the HP group. Gains in bench press lifting volume (P -5 ± 134; HP 225 ± 246 kg), the sum of bench press, squat, and power clean lifting volume (P 1,105 ± 429; HP 1,558± 645 kg), and total work performed during the first five 6-s sprints was significantly greater in the HP group.

Conclusion: The addition of creatine to the glucose/taurine/electrolyte supplement promoted greater gains in fat/bone-free mass, isotonic lifting volume, and sprint performance during intense resistance/agility training.

During explosive sprinting exercise, the energy supplied to repophosphorylate adenosine diphosphate (ADP) to adenosine triphosphate (ATP) is determined largely by the amount of phosphocreatine (PC) stored in the muscle (10,31). As PC stores become depleted, performance is likely to rapidly deteriorate because of the inability to resynthesize ATP at the rate required (29). Since the availability of PC stores in the muscle may significantly influence the amount of energy generated during brief periods of high intensity exercise, it has been hypothesized that increasing muscle creatine content may increase the availability of PC and allow for an accelerated rate of resynthesis of ATP during and following high intensity, short duration exercises (4,22,24,28,32).

Studies that have evaluated these hypotheses have found that supplementing the diet with approximately 20 g·d$^{-1}$ of creatine monohydrate for 2-7 d may elevate total creatine content in muscle by 10-20%, with 20-40% of the increased intramuscular creatine in the form of PC (4,5,20,22,24,28,32,38,41,47,51,52). In addition, studies suggest that creatine supplementation may affect myocardial (11,19) and skeletal muscle metabolism by accelerating the rate of ATP resynthesis during and/or following repeated bouts of high-intensity exercise (5,22,24,38). Theoretically this would improve repetitive sprint performance capacity.

In support of these hypotheses, studies indicate that creatine loading may improve high-intensity exercise performance in rowing (43), running (29,45), cycling (2,5,8,13,14,33), swimming (25), and resistance exercise (14,23,38,45,49). Studies have also indicated that creatine supplementation may increase total body weight (2,5,14,22,38,40,49) and/or lean body mass (14,45), possibly because of fluid retention (4) and/or stimulating protein synthesis (7,33,44). Finally, recent reports suggest that ingestion of carbohydrate with creatine enhances intramuscular creatine uptake (20,21) and glycogen deposition (21) and that creatine transport may be sodium dependent (26). Consequently, ingestion of glucose and sodium with creatine would theoretically provide additional ergogenic benefit.
However, not all studies investigating the ergogenic value of creatine supplementation have reported enhanced exercise performance\(^{(3,6,9,12,16,40-42,46)}\). In addition, while increases in total body weight have been reported in most studies, the effects of creatine supplementation on body composition are less clear. Finally, although no side effects have been reported other than weight gain\(^{(4)}\), little data are available evaluating the medical safety of supplementing the diet with creatine during training for prolonged periods of time. The purpose of this study was 1) to examine the effects of ingesting a supplement designed to enhance creatine uptake during intense resistance/agility training on body composition, maximal lifting volume, and sprint performance in well-trained athletes; and 2) to evaluate the effects of 28 d of creatine supplementation on clinical chemistry profiles.

### MATERIALS AND METHODS

**Subjects.** Twenty eight NCAA division IA football players undergoing winter/spring off-season resistance/football training at a major university in the mid-south region of the United States volunteered to participated in this study. Subjects were informed as to the experimental procedures and signed informed consent statements in adherence with the human subjects guidelines of The University of Memphis and the American College of Sports Medicine. Twenty five subjects who were descriptively (mean ± SEM) 19.9 ± 0.3 yr, 97.2 ± 4 kg, and 183 ± 2 cm completed the study. Remaining subjects were unable to complete the study because of injury, illness, and/or inability to comply with the study protocol.

Subjects signed statements indicating that they were not taking anabolic steroids and that they were aware that they may be subject to random drug testing during the study according to NCAA regulations. During the conduct of the study, 16 subjects were randomly selected by the NCAA for drug testing during two independent screenings. All drug tests were negative for the presence of anabolic/androgenic steroids according to NCAA criteria.

**Experimental design.** Subjects maintained their normal diet throughout the study. Meals consisted of *ad libitum* intake of a primary entree and a limited number of side entrees served at the team training table meals. Consequently, although the athletes were allowed to select their own foods and ingest food outside of the training table, diets of the athletes were similar. Moreover, subjects were not allowed to have ingested creatine, β-hydroxy β-methylbutyrate (HMB), or beta-agonists for an 8-wk period before the start of supplementation. Subjects were also instructed not to ingest any other nutritional supplements, proposed ergogenic aids, or nonprescription drugs during the course of the study.

During the first 2 wk of training, subjects participated in two familiarization sessions and completed presupplementation assessments. In the first familiarization session, the procedures of the study were explained, the subjects were weighed, and training and medical history forms were completed. In addition, the subjects practiced the cycle ergometer sprint test to be used in the study. This involved being seated on the CardiO\(_2\) computerized cycle ergometer (ErgometRx, St. Paul, MN) and having the subjects perform 12× 6-s maximal effort sprints with 30 s of rest between each sprint at a standardized work rate. Subjects performed one additional practice
sprint trial before presupplementation testing. In addition, subjects were instructed how to report nutritional intake on nutritional log sheets by a co-investigator trained in clinical nutrition.

Presupplementation assessments included: 1) a 4-d nutritional intake assessment (including one weekend day); 2) donation of an 8-h fasting venous blood sample; 3) measuring total body weight, body water, and body composition; 4) performance of low repetition maximal effort isotonic bench press and squat tests; and 5) performance of a 12 × 6-s sprint test on the cycle ergometer with 30-s rest recovery between sprints.

In a double-blind and randomized manner, subjects were then matched by total body weight and assigned to supplement their diet for 28 d with either a Phosphagen HP placebo (P) containing 99 g·d⁻¹ of glucose, 3 g·d⁻¹ of taurine, 1.1 g·d⁻¹ of disodium phosphate, and 1.2 g·d⁻¹ of potassium phosphate (N = 14) or Phosphagen HP (Experimental and Applied Sciences, Inc, Golden, CO) containing the P formulation with 15.75 g·d⁻¹ of HPCE pure creatine monohydrate (HP; N = 11). Supplements were prepared in powder form with similar texture, taste, and appearance and were independently packaged in generic foil packets for double-blind administration. Subjects mixed the supplement powder into approximately 0.25 L of water and ingested the solution with morning, mid-day, and evening meals.

Supplement packets were administered in blindly coded boxes containing a 15-d supply of the supplements. Subject compliance in taking the supplements was verified by having a research assistant collect empty supplement packets at evening meals throughout the study. Subjects had to turn in all empty packets to receive the next 15-d supply of supplements. In addition, subjects had to turn in all empty packets throughout the remainder of the study to receive the incentive for participating in the study (i.e., four cans of Phosphagain, Experimental & Applied Sciences). Consequently, compliance in taking the supplements was excellent.

During the 4-wk supplementation period, subjects participated in a standardized resistance and agility training program. The program consisted of 5 h·wk⁻¹ of heavy resistance training conducted on Monday, Tuesday, Thursday, and Friday afternoons, as well as a 3 h·wk⁻¹ of agility/sprint training conducted at 6:00 a.m. on Monday, Wednesday, and Friday mornings. Primary lifts performed included bench press, incline bench press, shoulder press, lateral pull downs, seated cable rows, upright rows, abdominals, squats, hip sled, gluteal/hamstring raises, power hang cleans, and clean and jerk. Lifts were prescribed in a structured program on a weekly rotation of lifts/sets/repetitions within a 4-wk microcycle (e.g., 1 to 3 sets of two to eight repetitions at intensities ranging from 60 to 95% of 1 RM(repetition maximum)). Agility training consisted of high intensity sprint and football agility drills. All training was performed under the supervision of certified strength coaches and/or assistant football coaches. Attendance was monitored and subjects who missed workouts were required to make them up according to team policy.

Following the 28-d supplementation period, subjects underwent postsupplementation assessments in a similar manner as the presupplementation tests. Therefore, diet was recorded for 4 d; subjects donated a fasting venous blood sample; body weight, body water, and body composition were determined; subjects performed the maximal effort low repetition test on the
isotonic bench press and squat; and the subjects performed the 12 × 6-s cycle ergometer sprint test with 30-s recovery between sprints.

Nutritional intake was monitored for 4 d before the initiation of supplementation and during the final week of supplementation. This was accomplished by having a registered dietitian and research assistants evaluate and record all food/fluid ingested during training table meals. In addition, subjects reported any additional food/fluids ingested between meals during this period. Nutritional records were analyzed by a registered dietitian using the Food Processor III nutritional analysis software (Nutritional Systems, Salem, OR).

Subjects observed an overnight 8-h fast before donating blood samples. Venous blood samples were obtained between 6:00 and 7:30 a.m. via venipuncture from an antecubital vein in the forearm using standard phlebotomy procedures. Venous blood was collected into 10-mL serum separation tubes (SST) and a 5-mL tube containing K₃. The SST tubes were centrifuged at 5,000 rev·min⁻¹ for 10-min using a Biofuge 17R centrifuge (Heraeus Inc., Germany). Samples were refrigerated and then shipped overnight in cold containers to Corning Clinical Laboratories (St. Louis, MO) for clinical analyses. A complete clinical chemistry panel (31 items) was run on serum samples using the Technicon DAX model 96-0147 automated chemistry analyzer using standard clinical procedures (Technicon Inc., Tarrytown, NY). Cell blood counts with percent differentials were run on whole blood samples using a Coulter STKS automated analyzer using standard procedures (Coulter Inc., Hialeah, FL).

Total body weight was measured on a calibrated digital scale with a precision of ± 0.02 kg (Sterling Scale Co., Southfield, MI). Total body water was estimated using a Valhalla 1990b Bioelectrical Impedance Analyzer (San Diego, CA).

Whole body (excluding cranium) body composition measurements were determined using a Hologic QDR-2000 dual energy x-ray absorptiometer (Waltham, MA) with the Hologic version V 7, REV F software. This system measures the amount of bone, fat, and fat-free/soft tissue mass which falls within standardized density ranges using dual energy x-ray absorptiometry methodology (DEXA). The DEXA scans regions of the body (right arm, left arm, trunk, right leg, and left leg) to determine the amount of bone mass, fat mass, and fat-free/soft tissue mass within each region. The scanned bone, fat, and fat-free/soft tissue mass for each region are then subtotaled to determine whole body (excluding cranium) values. Percent body fat is calculated by dividing the amount of measured fat mass by total scanned mass (sum of bone mass, fat mass, and fat-free/soft tissue mass). It should be noted that the DEXA does not consider total body weight when the densities of bone, fat, and fat-free/soft tissue mass are determined. The DEXA records only the amount of tissue measured within the standardized density ranges. Therefore, the scanned total body mass (adding an estimate for the cranium mass) may not equal total body weight. DEXA has been shown to be a highly reliable (r = 0.99) and precise method (coefficient of variation of 0.5-1%) for determining individual body composition segments.

Quality control (QC) calibration procedures were performed on a spine phantom (Hologic X-CALIBER Model DPA/QDR-1 anthropometric spine phantom) before each testing session. The spine phantom was scanned in the AP single-beam mode, array mode, and lateral array modes. Analysis of QC scans were performed by comparing daily QC scans with a Hologic reference
scan of the phantom. Data from the daily QC scans were then entered into the database and compared with factory values. Values for daily QC scans were plotted for both bone mineral content (BMC) and bone mineral density (BMD) in all mentioned modes. Tolerance levels for the QC scans were set at ± 1 SD from the unit mean, which is determined by Hologic for each individual unit. Mean coefficients of variation in BMC and BMD measurements obtained in the lateral and array modes ranged between 0.41 to 0.55% throughout the life of the unit. Subjects were positioned according to standardized criteria during the initial scan. This position was referenced into the computer for positioning of subjects in subsequent trials. DEXAs were performed by technicians certified in radiology to perform DEXAs.

Subjects performed maximal effort repetition tests on the isotonic bench press, squat, and power clean to determine lifting volume. This strength testing approach was selected in consultation with the strength coaches because it more closely represented the type of resistance training the athletes were involved in during the study (i.e., a 4-wk periodized cycle of mid-range repetitions). Basically, this involved having the athletes warm up and then perform a maximal effort repetition test with a weight that the strength coaches estimated the athlete could lift between four and eight times based on training lifting performance. Lifting volume was determined by multiplying the amount of weight lifted by the number of repetitions performed. Total lifting volume was determined by adding the sum of bench press, squat, and power clean lifting volumes. All isotonic test sets were performed under supervision of certified strength coaches using standardized lifting criteria (17,36,50).

The sprint tests were performed on a computerized CardiO2 cycle ergometer equipped with toe clips at a standardized work rate of 3.85 J·kg⁻¹·rev⁻¹ (ErgometRx Corp., St. Paul, MN). Seat position was standardized between trials. The ergometer was connected via an RS232 parallel interface to a Dell 466/Le Optiplex computer (Dell Computer Corp., Austin, TX) using ErgometRx Cardioscribe and Exerscribe software (ErgometRx Corp.). Crank frequency was measured using a crystal referenced optic encoder with a precision range of 0-200 rev·min⁻¹ and an accuracy of ± 1 rev·min⁻¹. Pedal torque was determined by a calibrated strain gauge with a range of 0 to 2,000 W and an accuracy of ± 1%. Data were collected and downloaded into the computer at 0.5-s intervals.

**Statistical analysis.** Nutritional, hematological, body composition, and strength data were analyzed by a 2 × 2 repeated measures ANOVA using SPSS for Windows Version 7.5 software. Delta scores (post and pre values) were calculated on selected variables and analyzed by one-way ANOVA. To normalize differences between groups in presupplementation sprint performance, Day 28 work data were analyzed by ANCOVA using Day 0 data as the covariate. Tukey post hoc procedures were performed on the adjusted means to examine significant group × sprint effects. Data are presented as means ± SDs of means. Data were considered significantly different when the probability of error was 0.05 or less.
Side effects. Subjects tolerated the supplementation protocol well with no reports of gastrointestinal distress and/or medical problems/symptoms. In addition, there was no evidence of muscular cramping during resistance/agility training sessions or during performance trials.

Nutritional intake. No significant differences were observed between groups in mean estimated total energy intake (P 42 ± 10; HP 39± 8 kcal·kg⁻¹·d⁻¹, P = 0.49), carbohydrate intake (P 5.3 ± 0.9; HP 4.8 ± 1.0 g·kg⁻¹·d⁻¹, P = 0.14), fat intake (P 1.5± 0.4; HP 1.6 ± 0.4 g·kg⁻¹·d⁻¹,P = 0.62), or protein intake (P 1.7 ± 0.6; HP 1.6 ± 0.4 g·kg⁻¹·d⁻¹, P = 0.70).

Clinical chemistry profiles. All blood variables evaluated remained within normal limits for individuals engaged in heavy exercise training. No significant group × time interactions were observed in plasma glucose, carbon dioxide, urea nitrogen, uric acid, total protein, albumin, alkaline phosphatase, sodium, potassium, chloride, calcium, ionized calcium, phosphorus, leukocytes, neutrophils, lymphocytes, monocytes, eosinophils, basophils, hemoglobin, hematocrit, total bilirubin, total iron, platelets, red blood cells, red blood cell distribution width, mean corpuscular volume, or mean platelet volume.

Tables 1, 2, and 3 present remaining blood variables evaluated. Creatinine and globulin levels were significantly increased in the HP group, whereas the ratio of blood urea nitrogen/creatinine was significantly increased in the P group. In addition, the ratio of albumin/globulin was significantly decreased in the HP group. Results also provide some evidence of a mild elevation in creatine kinase (CK), lactate dehydrogenase (LDH), aspartate aminotransferase (AST), and alanine aminotransferase (ALT) activities in the HP group with no effects on g-glutamyltransferase (GGT). Subjects in the HP group also exhibited some evidence of an improved lipid profile (i.e., 13% increased in HDL, a 13% decrease in VLDL, and a 7% decrease in the ratio of HDL/CHOL).

Total body weight and body water. Total body weight was significantly increased in both groups. However, gains in total body weight were significantly greater in the HP group (P 0.85 ± 2.2; HP 2.42± 1.4 kg, P = 0.05). No significant differences were observed between groups in total body water changes expressed as a percentage of total body weight (P -0.04 ± 0.7; HP -0.01 ± 0.6%, P = 0.93).

Body composition. Table 4 presents DEXA determined body composition data obtained on days 0 and 28 of supplementation, while Figure 1 presents mean changes in body composition values from Day 0. No significant differences were observed in mean changes in bone mass, fat mass, or percent body fat between the P and HP groups. Gains in scanned total body mass and fat/bone-free mass were significantly greater in the HP group.
Strength. Subjects in the HP group observed a significantly greater increase in bench press lifting volume (P = 5 ± 134; HP 225± 246 kg, P = 0.002). No significant differences were observed in changes in squat (P = 267 ± 308; HP 327 ± 350 kg, P = 0.56) or power clean lifting volume (P = 921 ± 326; HP 1100± 485 kg, P = 0.28). However, changes in total lifting volume (sum of bench press, squat, and power clean) were significantly greater in the HP group (P = 1,105 ± 429; HP 1,558 ± 645 kg, P = 0.05).

Sprint performance. Figure 2 presents Day 0 and Day 28 mean work (J) responses observed for the P and HP groups during the 12 × 6-s sprints, while Figure 3 presents mean changes in work (J) for the 12 × 6-s sprint test. ANCOVA revealed a significant group × sprint effect (P = 0.006) in Day 28 work values. Post hoc analysis revealed that work was significantly greater in the HP group during sprints 1 to 5, with differences between groups dissipating thereafter. Mean improvement in total accumulated work to perform the 12 × 6 sprints was 51% greater in the HP group; however, this difference was not significantly different between groups (P = 4,599 ± 7,427; HP 6,951 ± 7,718 J, P = 0.45).

DISCUSSION

Results of the present study indicate that 28 d of creatine supplementation (15.75 g·d⁻¹) with glucose, taurine, and electrolyte during resistance/agility training promoted significantly greater gains in fat/bone-free mass, isotonic lifting volume, and sprint performance in comparison with ingestion of the glucose, taurine, and electrolyte formulation alone. These findings support previous reports that creatine supplementation may increase total body weight (2-8,14,20,38,40,49) and/or lean body mass (14,45), promote greater gains in strength (14,45,49), and improve intense exercise performance and/or recovery (2,5,13,14,22,24,25,29,33,38,43,45). Although the etiology of these improvements remains to be determined, our results provide additional evidence that creatine supplementation may enhance physiological adaptations to resistance/agility training.

Clinical chemistry responses. Although creatine supplementation has become a popular nutritional supplement among athletes (35), little is known regarding the medical safety of short-term (<7-d) or long-term (>7-d) creatine supplementation during training at the proposed ergogenic doses (i.e., 10-20 g·d⁻¹). Short-term creatine supplementation has been reported to increase erythrocytic creatine content and mildly increase serum creatine (20,21,28,32) and creatinine levels (32). However, studies conducted in an older subject population over an 8-wk period, at daily doses ranging from 10-20 g, found no significant effects on creatinine concentrations. In the present study, ingestion of creatine with glucose, taurine, and electrolytes for 28 d resulted in a small but significant increase in fasting serum creatinine levels. Clinically, serum creatinine is
used as an indirect marker of renal stress \(^{(27)}\). Normal fasting serum creatinine concentrations in untrained subjects typically range between 90-110μmol·L\(^{-1}\) but may increase up to ten-fold under certain pathological conditions \(^{(27)}\). Intense exercise typically increases serum creatinine levels by 20 to 50 μmol·L\(^{-1}\) as well as promotes urinary creatinine excretion\(^{(4,10,20,21,32)}\). The exercise-induced increase in serum and urinary creatinine levels has been suggested to reflect an increased release and cycling of intramuscular creatine as a consequence of myofibrillar protein turnover\(^{(4,10,15)}\). While the concentrations observed after HP supplementation remained within normal limits for individuals engaged in intense training (i.e., 100 to 150μmol·L\(^{-1}\)), results suggest that creatine supplementation\((15.75\text{ g·d}^{-1}\text{ for 28 d})\) may increase fasting serum creatinine levels. The etiology and clinical significance of the mild elevation in serum creatinine levels remains to be determined.

Second, creatine supplementation was associated with a moderate increase in muscle and liver enzyme efflux. In active populations, elevations in creatinine and muscle/liver enzymes are typically used as indicators of training/exercise intensity \(^{(4,10,27)}\). In this regard, the more intense the training/exercise bout, the higher the muscle and liver enzyme efflux. Consequently, it could be argued that although the subjects underwent similar training, subjects in the HP group may have been able to maintain a greater training intensity during the program, promoting greater muscle/liver enzyme efflux. However, long-term supplementation (8-wk) of creatine in older individuals not participating in intense training also has been associated with moderate increases in CK concentrations \(^{(1)}\). Interestingly though, the ratio of urea nitrogen/creatinine was unchanged in the HP group while being significantly elevated in the P group. Increases in the ratio of urea nitrogen/creatinine are used as a general marker of catabolism \(^{(27)}\). Consequently, this finding suggests that despite the moderate increases in serum muscle and liver enzyme efflux observed, subjects in the HP group may have experienced less catabolism and/or greater nitrogen retention during training in comparison with the placebo group. This finding supports contentions that creatine supplementation may allow the athlete to maintain a greater training volume/intensity and thereby improve the quality of training. Additional research should evaluate the effects of creatine supplementation on training volume, training intensity, muscle/liver enzyme efflux, and markers of skeletal muscle proteolysis.

Third, analysis of blood lipid data provides some additional evidence that creatine supplementation may affect blood lipids. In this regard, HDL concentrations were significantly increased (13%) while there was some evidence that VLDL levels (-13%) and the ratio of total cholesterol to HDL levels (-7%) decreased in the creatine group. These findings support the report of Earnest et al. \(^{(15)}\) that creatine supplementation significantly decreased total cholesterol, triglycerides, and VLDL in moderately hyperlipidemic, physically active male and female subjects. Additional research should evaluate the potential lipid modulating effects of creatine supplementation.

**Body composition.** Short-term creatine supplementation (5 to 7 d) has been reported to increase total body mass by approximately 0.6 to 1.1 kg \(^{(2,5,14,20,38,40,49)}\). The increase in total body mass has been suggested to be a result of an increase in total body water content \(^{(4)}\) and/or a creatine-stimulated increase in myofibrillar protein synthesis \(^{(7,33,44)}\). While we are not aware of any studies reporting a disproportionate increase in total body water content following creatine supplementation, studies have reported that creatine promotes amino acid uptake and stimulates
myofibrillar protein synthesis (7,33). Moreover, there is evidence in patient populations that depletion of intramuscular creatine is associated with atrophy of Type II muscle fibers and that creatine supplementation (1.5 g·d⁻¹ for 1 yr) in creatine depleted gyrate atrophy patients significantly increased total body weight by 10% and Type II muscle fiber diameter by 34% (44).

Unfortunately, few studies have evaluated the effects of creatine supplementation on body composition. Earnest et al. (14) reported that 28 d of creatine supplementation (20 g·d⁻¹) during resistance training significantly increased total body mass by 1.7 kg (P < 0.05) and that gains in hydrostatically determined fat-free mass accounted for 1.5 kg of the total body mass gain (P = 0.054). In addition, Stout et al. (45) found that 8 wk of creatine supplementation (21 g·d⁻¹ for 5 d and 10.5 g·d⁻¹ for 51 d) during off-season football resistance/agility training did not significantly increase DEXA determined fat-free mass (2.6± 2.0 kg) in comparison with a glucose placebo (-0.01 ± 2.6 kg). However, addition of glucose, taurine, and electrolytes to the creatine supplement (Phosphagen HP as used in the present study) promoted significant increases in fat-free mass (2.9 ± 1.5 kg) in comparison with those in the glucose placebo.

In the present study, creatine supplementation with glucose, taurine, and electrolytes promoted significantly greater gains in total body mass (P 0.85± 2.2; HP 2.42 ± 1.4 kg), scanned body mass (P 0.77 ± 1.8; HP 2.22 ± 1.5 kg), and fat/bone-free mass (P 1.33 ± 1.1; HP 2.43 ± 1.4 kg) in comparison with ingestion of the glucose, taurine, electrolyte supplement alone. Moreover, the increases in body mass could not be explained by disproportionate increases in total body water content as determined by bioelectrical impedance. These findings provide additional evidence that creatine supplementation may promote lean tissue accretion during resistance/agility training and that ingestion of creatine with glucose, taurine, and electrolytes may promote greater gains in fat/bone-free mass (2.43 ± 1.4 kg) than previously reported (14) with creatine supplementation alone (i.e., 1.5 kg). However, additional research is necessary to evaluate the effects of creatine supplementation on body composition, fluid retention/total body water content using more precise methods, and protein synthesis. Moreover, additional research should evaluate the potential additive and/or synergistic effects that creatine, glucose, taurine, sodium phosphate, and potassium phosphate may have on lean tissue accretion during training.

Performance. The majority of studies investigating the effects of creatine supplementation have focused on the potential ergogenic value during exercise following short-term loading periods (i.e., 15-20 g·d⁻¹ for 5-7 d). These studies have indicated that creatine supplementation improved: 1000-m rowing performance (43); repetitive running (29), cycling (2,5,8,13,14,34), and swimming (25) sprint performances; the amount of work performed during repeated sets of isokinetic contractions (23,38); and gains in strength/lifting volume (38,49). However, other studies have reported no ergogenic value on single-sprint performance in swimmers (9,40), 60-m sprint capacity in field hockey and baseball players (42), cycling sprint performance (6,12,16,41), submaximal endurance exercise (46), or high-intensity endurance running (3).

Fewer studies have investigated the effects of longer periods of creatine supplementation on exercise performance. Grindstaff et al. (25) found that 9 d of creatine supplementation (21 g·d⁻¹) significantly improved swim performance times during 3× 100-m freestyle swims with 60-s rest recovery and arm ergometer performance when performing 3 × 20-s sprints with 60-s rest recovery in competitive junior swimmers. Earnest et al. (14) found that 28 d of creatine
supplementation (20 g·d⁻¹) during resistance training significantly increased: 3 × 30-s maximal effort cycling performance with 5-min rest recovery between bouts; 1 RM bench press performance; and bench press lifting volume at 70% of 1 RM.

Similarly, Stout et al. (45) reported that 8 wk of creatine supplementation (21 g·d⁻¹ for 5 d and 10.5 g·d⁻¹ for 51 d) did not significantly improve changes 1 RM bench press (placebo 13.1 ± 9.6; creatine 17.5 ± 9.3 kg), vertical jump performance (placebo 1.3 ± 3.5; creatine 5.1 ± 3.8 cm), or 100-yd sprint times (placebo -0.02 ± 0.09; creatine -0.24 ± 0.16-s) during off-season football resistance/agility training. However, addition of glucose, taurine, and electrolytes to the creatine supplement(Phosphagen HP) promoted significant increases in 1 RM bench press (28.8± 13.0 kg), vertical jump performance (5.6 ± 2.9 cm), and 100-yard sprint times (-0.31 ± 0.1 s) in comparison with those of the placebo.

Results of the present study support these findings in that subjects in the creatine supplemented group had greater gains in bench press lifting volume and cycle ergometer sprint performance during the first five 6-s sprints. Collectively, these findings suggest that 9-56 d of creatine supplementation may enhance the quality of training leading to improved repetitive sprint performance and/or strength. However, additional research is necessary to determine whether the improved sprint and strength performance would result in greater performance in various athletic events.

Back to Top | Article Outline

**SUMMARY**

Results indicate that 28 d of creatine supplementation (15.75 g·d⁻¹) with glucose, taurine, and electrolytes promoted significantly greater gains in fat/bone-free mass, upper extremity lifting volume, and sprint performance during resistance/agility training in well-trained athletes in comparison with ingesting the glucose, taurine, and electrolyte formulation alone. These findings support previous reports that creatine supplementation may provide ergogenic benefit. Additional research should evaluate: 1) the role of creatine supplementation on protein turnover, serum creatinine kinetics, muscle and liver enzyme efflux, lipid and cholesterol metabolism, fluid retention/total body water, and lean tissue accretion; 2) the effects of creatine supplementation on training volume/intensity and performance in a variety of sports events; 3) the medical safety of long-term supplementation of creatine; and 4) the additive and/or synergistic role that creatine, glucose, taurine, sodium phosphate, and potassium phosphate may have on body composition and performance.

We would like to thank the subjects who participated in this study and the laboratory assistants in Exercise & Sport Sciences Laboratory, the Universities Prevention Center, and in the Department of Athletics at The University of Memphis who assisted in data acquisition and analysis.

This study was funded through a research grant provided to The University of Memphis from Experimental and Applied Sciences, Golden, CO. Investigators from The University of Memphis independently collected, analyzed, and interpreted data from this study and have no financial...
interest in the outcome of results reported. A. L. Almada is cofounder and a consultant for Experimental and Applied Sciences, Inc. and served as a consultant and liaison between investigators at The University of Memphis and the granting agency. Presentation of results in this study does not constitute endorsement of the product investigated by The University of Memphis nor the American College of Sports Medicine.

Address for correspondence: Richard B. Kreider, Ph.D., FACSM, Exercise& Sport Sciences Laboratory, Department of Human Movement Sciences & Education, The University of Memphis, Memphis, TN 38152. E-mail: kreider.richard@coe.memphis.edu.

Back to Top | Article Outline

REFERENCES


[Cited Here...](#) | [PubMed](#) | [CrossRef](#)

[Cited Here...](#) | [PubMed](#)

[Cited Here...](#)

[Cited Here...](#) | [PubMed](#)

[Cited Here...](#)

[Cited Here...](#) | [PubMed](#)

[Cited Here...](#) | [PubMed](#) | [CrossRef](#)

[Cited Here...](#)

[Cited Here...](#) | [PubMed](#) | [CrossRef](#)

[Cited Here...](#)


Cited By:

This article has been cited 204 time(s).

Sports Medicine
Effects of creatine supplementation on exercise performance
Demant, TW; Rhodes, EC
Sports Medicine, 28(1): 49-60.

Archivos Latinoamericanos De Nutricion
Relation of some nutritional supplements and physical performance
Gomes, MD; Tirapegui, J

Molecular and Cellular Biochemistry
Long-term creatine supplementation does not significantly affect clinical markers of health in athletes
Kreider, RB; Melton, C; Rasmussen, CJ; Greenwood, M; Lancaster, S; Cantler, EC; Milnor, P; Almada, AL
Molecular and Cellular Biochemistry, 244(1): 95-104.
Journal of Applied Physiology
Effects of creatine supplementation and exercise training on fitness in men 55-75 yr old
Eijnde, BO; Van Leemputte, M; Goris, M; Labarque, V; Taes, Y; Verbessem, P; Vanhees, L; Ramaekers, M; Eynde, BV; Van Schuylenbergh, R; Dom, R; Richter, EA; Hespel, P
10.1152/japplphysiol.00891.2002
CrossRef

Pediatric Exercise Science
Behavioral and psychological factors related to the use of nutritional ergogenic aids among preadolescents
Pesce, C; Donati, A; Magri, L; Cereatti, L; Giampietro, M; Monacelli, C; Zelli, A
Pediatric Exercise Science, 16(3): 231-249.

Primary Care
Sports pharmacology and ergogenic aids
Ellender, L; Linder, MM
Primary Care, 32(1): 277-286.
10.1016/j.pop.2004.11.008
CrossRef

Journal of Nutrition Health & Aging
Creatine monohydrate and resistance training increase bone mineral content and density in older men
Chilibeck, PD; Chrusch, MJ; Chad, KE; Davison, KS; Burke, DG

Journal of Cystic Fibrosis
Dietary supplementation with multiple micronutrients: No beneficial effects in pediatric cystic fibrosis patients
Oudshoorn, JH; Klijn, PHC; Hofman, Z; Voorbij, HAM; van der Ent, CK; Berger, R; Houwen, RHJ
10.1016/j.jcf.2006.05.005
CrossRef

British Journal of Sports Medicine
Creatine supplementation does not affect clinical health markers in football players
Cancela, P; Ohanian, C; Cuitino, E; Hackney, AC
British Journal of Sports Medicine, 42(9): 731-735.
10.1136/bjsm.2007.030700
CrossRef

International Journal of Sport Nutrition
Oral creatine supplementation and upper extremity anaerobic response in females
Hamilton, KL; Meyers, MC; Skelly, WA; Marley, RJ

International Journal of Sport Nutrition and Exercise Metabolism
The effect of whey protein supplementation with and without creatine monohydrate combined with resistance training on lean tissue mass and muscle strength
Burke, DG; Chilibeck, PD; Davison, KS; Candow, DG; Farthing, J; Smith-Palmer, T

Journal of Animal Science
Creatine monohydrate supplementation and the quality of fresh pork in normal and halothane carrier pigs
Maddock, RJ; Bidner, BS; Carr, SN; McKeith, FK; Berg, EP; Savell, JW

Animal Feed Science and Technology
Effect of creatine monohydrate on finishing pig growth performance, carcass characteristics and meat quality
James, BW; Goodband, RD; Unruh, JA; Tokach, MD; Nelssen, JL; Dritz, SS; O'Quinn, PR; Andrews, BS
Animal Feed Science and Technology, 96(): 135-145.
PII S0377-8401(01)00346-7
CrossRef

Journal of Applied Physiology
Creatine supplementation influences substrate utilization at rest
Huso, ME; Hampl, JS; Johnston, CS; Swan, PD
10.1152/japplphysiol.01170.2001
CrossRef

Journal of Applied Physiology
Effect of dietary supplements on lean mass and strength gains with resistance exercise: a meta-analysis
Nissen, SL; Sharp, RL
10.1152/japplphysiol.00755.2002
CrossRef

Muscle & Nerve
Creatine monohydrate supplementation does not increase muscle strength, lean body mass, or muscle phosphocreatine in patients with myotonic dystrophy type 1
Tarnopolsky, M; Mahoney, D; Thompson, T; Naylor, H; Doherty, TJ
10.1002/mus.10527
CrossRef

Sports Medicine
Effects of resistance training on older adults
Hunter, GR; McCarthy, JP; Bamman, MM

Journal of Physiology-London
Creatine supplementation augments the increase in satellite cell and myonuclei number in human skeletal muscle induced by strength training
Olsen, S; Aagaard, P; Kadi, F; Tufekovic, G; Verney, J; Olesen, JL; Suetta, C; Kjaer, M
Creatine supplementation: Safe as steak? Culpepper, RM
Southern Medical Journal, 91(9): 890-892.

Creatine monohydrate increases strength in patients with neuromuscular disease
Tarnopolsky, M; Martin, J

Effects of modified tall oil and creatine monohydrate on growth performance, carcass characteristics, and meat quality of growing-finishing pigs
O'Quinn, PR; Andrews, BS; Goodband, RD; Unruh, JA; Nelssen, JL; Woodworth, JC; Tokach, MD; Owen, KQ

Creatine supplementation during resistance training in college football athletes
Bemben, MG; Bemben, DA; Loftiss, DD; Knehans, AW
Medicine and Science in Sports and Exercise, 33(): 1667-1673.

Creatine-dextrose and protein-dextrose induce similar strength gains during training
Tarnopolsky, MA; Parise, G; Yardley, NJ; Ballantyne, CS; Olatunji, S; Phillips, SM
Medicine and Science in Sports and Exercise, 33(): 2044-2052.

Performance-enhancing drug use in the young athlete
Metzl, JD

Oral creatine supplementation and skeletal muscle metabolism in physical exercise
Mesa, JLM; Ruiz, JR; Gonzalez-Gross, MM; Sainz, AG; Garzon, MJC
Sports Medicine, 32(): 903-944.

Creatine supplementation enhances isometric strength and body composition improvements following strength exercise training in older adults
Brose, A; Parise, G; Tarnopolsky, MA
Journals of Gerontology Series A-Biological Sciences and Medical Sciences, 58(1): 11-19.
Racette, SB

Archives of Physical Medicine and Rehabilitation
Musculoskeletal rehabilitation and sports medicine. 4. Miscellaneous sports medicine topics
Smith, J; Wilder, RP
Archives of Physical Medicine and Rehabilitation, 80(5): S68-S89.

International Journal of Sport Nutrition and Exercise Metabolism
The effects of beta-hydroxy-beta-methylbutyrate (HMB) and HMB/creatine supplementation on indices of health in highly trained athletes
Crowe, MJ; O'Connor, DM; Lukins, JE

Journal of Sports Medicine and Physical Fitness
Is the use of oral creatine supplementation safe?
Bizzarini, E; De Angelis, L

Journal of Renal Nutrition
Acute renal failure in a young weight lifter taking multiple food supplements, including creatine monohydrate
Thorsteinsdottir, B; Grande, JP; Garovic, VD
10.1053/j.jrn.2006.04.025 CrossRef

Japanese Journal of Physical Fitness and Sports Medicine
The effect of oral creatine supplementation on power-duration hyperbolic curve in humans
Kitahara, Y; Miura, A; Inaki, M; Kuno, S; Fukuba, Y

International Journal of Sport Nutrition
The effect of continuous low dose creatine supplementation on force, power, and total work
Burke, DG; Silver, S; Holt, LE; Smith-Palmer, T; Culligan, CJ; Chilibeck, PD
International Journal of Sport Nutrition, 10(3): 235-244.

Annals of Pharmacotherapy
The effect of creatine intake on renal function
Pline, KA; Smith, CL
10.1345/sph.1E628 CrossRef

Journal of Sports Science and Medicine
Creatine supplementation and swim performance: A brief review
Hopwood, MJ; Graham, K; Rooney, KB
European Journal of Sport Science
Building muscle: nutrition to maximize bulk and strength adaptations to resistance exercise training
Tarnopolsky, MA
10.1080/17461390801919128
CrossRef

Agro Food Industry Hi-Tech
Creatine's effects on thermoregulation: should we be concerned?
Rosene, JM
Agro Food Industry Hi-Tech, 18(5): XIV-XVI.

Applied Physiology Nutrition and Metabolism-Physiologie Appliquée Nutrition Et Metabolisme
The potential benefits of creatine and conjugated linoleic acid as adjuncts to resistance training in older adults
Tarnopolsky, MA; Safdar, A
10.1139/H07-142
CrossRef

Plos One
Creatine Fails to Augment the Benefits from Resistance Training in Patients with HIV Infection: A Randomized, Double-Blind, Placebo-Controlled Study
Sakkas, GK; Mulligan, K; DaSilva, M; Doyle, JW; Khatami, H; Schleich, T; Kent-Braun, JA; Schambelan, M
Plos One, 4(2): -. ARTN e4605
CrossRef

Canadian Journal of Applied Physiology-Revue Canadienne De Physiologie Appliquée
Creatine supplementation: Exploring the role of the creatine kinase/phosphocreatine system in human muscle
Hespel, P; Op ’t Eijnde, B; Derave, W; Richter, EA

Amyotrophic Lateral Sclerosis and Other Motor Neuron Disorders
No effect of creatine on respiratory distress in amyotrophic lateral sclerosis
Drory, VE; Gross, D
Amyotrophic Lateral Sclerosis and Other Motor Neuron Disorders, 3(1): 43-46.

International Journal of Sport Nutrition and Exercise Metabolism
Effects of long-term creatine supplementation on liver and kidney functions in American college football players
Mayhew, DL; Mayhew, JL; Ware, JS
Effect of creatine supplementation on body composition and performance: A meta-analysis
Branch, JD

European Journal of Applied Physiology
Short-term creatine supplementation does not improve muscle activation or sprint performance in humans
Kinugasa, R; Akima, H; Ota, A; Ohta, A; Sugiura, K; Kuno, S
10.1007/s00421-003-0970-8
CrossRef

Creatine Monohydrate and Conjugated Linoleic Acid Improve Strength and Body Composition Following Resistance Exercise in Older Adults
Tarnopolsky, M; Zimmer, A; Paikin, J; Safdar, A; Aboud, A; Pearce, E; Roy, B; Doherty, T
Plos One, 2(): -.
ARTN e991
CrossRef

Creatine supplementation during college football training does not increase the incidence of cramping or injury
Greenwood, M; Kreider, RB; Melton, C; Rasmussen, C; Lancaster, S; Cantler, E; Milnor, P; Almada, A
Molecular and Cellular Biochemistry, 244(1): 83-88.

Creatine supplementation: effects on urinary excretion and anaerobic performance
Havenetidis, K; Bourdas, D

Role of submaximal exercise in promoting creatine and glycogen accumulation in human skeletal muscle
Robinson, TM; Sewell, DA; Hultman, E; Greenhaff, PL

Effect of meal timing after resistance exercise on hindlimb muscle mass and fat accumulation in trained rats
Suzuki, M; Doi, T; Lee, SJ; Okamura, K; Shimizu, S; Okano, G; Sato, Y; Shimomura, Y; Fushiki, T

Creatine supplementation - Part I: Performance, clinical chemistry, and muscle volume
Kamber, M; Koster, M; Kreis, R; Walker, G; Boesch, C; Hoppeler, H
Medicine and Science in Sports and Exercise, 31(): 1763-1769.

International Journal of Sports Medicine
Effect of exogenous creatine supplementation on muscle PCr metabolism
Francaux, M; Demeure, R; Goudemant, JF; Poortmans, JR

International Journal of Sport Nutrition and Exercise Metabolism
Effect of creatine on body composition and strength gains after 4 weeks of resistance training in previously nonresistance-trained humans
Kilduff, LP; Pitsiladis, YP; Tasker, L; Attwood, J; Hyslop, P; Dailly, A; Dickson, I; Grant, S

Journal of Nutrition Health & Aging
The effects of creatine and whey protein supplementation on body composition in men aged 48 to 72 years during resistance training
Eliot, KA; Knehans, AW; Bemben, DA; Witten, MS; Carter, J; Bemben, MG

Journal of the American College of Nutrition
Creatine supplementation and exercise performance: An update
Williams, MH; Branch, JD

Ernahrungs-Umschau
Creatine - harmless food or doping agent with side-effects?
Konig, D; Berg, A

Mayo Clinic Proceedings
Creatine use among a select population of high school athletes
Smith, J; Dahm, DL
Mayo Clinic Proceedings, 75(): 1257-1263.

American Family Physician
Ergogenic aids: Counseling the athlete
Ahrendt, DM
American Family Physician, 63(5): 913-922.

International Journal of Sport Nutrition and Exercise Metabolism
Creatine monohydrate supplementation enhances high-intensity exercise performance in males and females
Tarnopolsky, MA; MacLennan, DP

Journal of Physiology-London
Oral creatine supplementation facilitates the rehabilitation of disuse atrophy and alters the
expression of muscle myogenic factors in humans
Hespel, P; Eijnde, BO; Van Leemputte, M; Urso, B; Greenhaff, PL; Labarque, V; Dymarkowski, S; Van Hecke, P; Richter, EA

International Journal of Sport Nutrition and Exercise Metabolism
Acute creatine supplementation and performance during a field test simulating match play in elite female soccer players
Cox, C; Mujika, I; Tumilty, D; Burke, L

Pediatric Clinics of North America
Supplements and drugs used to enhance athletic performance
Congeni, J; Miller, S
PII S0031-3955(01)00013-X
CrossRef

Military Medicine
Health assessment of US Army Rangers
Deuster, PA; Sridhar, A; Becker, WJ; Coll, R; O'Brien, KK; Bathalon, G
Military Medicine, 168(1): 57-62.

Journal of Sports Medicine and Physical Fitness
Effects of beta-hydroxy-beta-methylbutyrate and creatine monohydrate supplementation on the aerobic and anaerobic capacity of highly trained athletes
O'Connor, DM; Crowe, MJ

Journal of Sports Sciences
Nutrition for the sprinter
Tipton, KD; Jeukendrup, AE; Hespel, P
10.1080/02640410701607205
CrossRef

Journal of the International Society of Sports Nutrition
Does creatine supplementation improve the plasma lipid profile in healthy male subjects undergoing aerobic training?
Gualano, B; Ugrinowitsch, C; Artioli, GG; Benatti, FB; Scaglusi, FB; Harris, RC; Lancha, AH
Journal of the International Society of Sports Nutrition, 5(): -.
ARTN 16
CrossRef

Nutrition Research
Effects of 8 weeks of creatine supplementation on exercise performance and fat-free weight in football players during training
Stout, J; Eckerson, J; Noonan, D; Moore, G; Cullen, D
Clinics in Sports Medicine
Creatine supplementation - Its role in human performance
Kraemer, WJ; Volek, JS
Clinics in Sports Medicine, 18(3): 651-+.

Physiological Reviews
Creatine and creatinine metabolism
Wyss, M; Kaddurah-Daouk, R
Physiological Reviews, 80(3): 1107-1213.

British Journal of Sports Medicine
Dietary creatine supplementation does not affect some haematological indices, or indices of muscle damage and hepatic and renal function
Robinson, TM; Sewell, DA; Casey, A; Steenge, G; Greenhaff, PL

Journal of the American College of Surgeons
Understanding and managing cancer cachexia
MacDonald, N; Easson, AM; Mazurak, VC; Dunn, GP; Baracos, VE
10.1016/S1072-7515(03)00382-X
CrossRef

Journal of Athletic Training
A comparison of thermoregulation with creatine supplementation between the sexes in a thermoneutral environment
Rosene, JM; Whitman, SA; Fogarty, TD

International Journal of Sports Medicine
The use of nutritional supplements among master athletes
Striegel, H; Simon, P; Wurster, C; Niess, AM; Ulrich, R
CrossRef

Journal of Sports Sciences
Dietary supplements for football
Hespel, P; Maughan, RJ; Greenhaff, PL
10.1080/02640410500482974
CrossRef

Military Medicine
The effect and safety of short-term creatine supplementation on performance of push-ups
Armentano, MJ; Bremer, AK; Hedman, TL; Solomon, ZT; Chavez, J; Kemper, GB; Salzberg, D; Battafarano, DF; Christie, DS
Military Medicine, 172(3): 312-317.
Clinical Nephrology
How we estimate GFR - a pitfall of using a serum creatinine-based formula
Refaie, R; Moochhala, SH; Kanagasundaram, NS

Proceedings of the Nutrition Society
Isotopes in nutrition research
Young, VR; Ajami, A

Creatine: From Basic Science To Clinical Application
Impact of oral creatine supplementation on muscle performance during training and rehabilitation
Hespel, P; ’t Eijnde, BO; Vandenbergh, K; Van Leemputte, M
Creatine: From Basic Science To Clinical Application, 14(): 65-73.

Journal of Sports Medicine and Physical Fitness
Creatine as nutritional supplementation and medicinal product
Benzi, G; Ceci, A

Deutsche Lebensmittel-Rundschau
Health assessment of creatine as a dietary supplement
Mertschenk, B; Gloxhuber, C; Wallimann, T
Deutsche Lebensmittel-Rundschau, 97(7): 250-257.

Molecular and Cellular Biochemistry
Effects of creatine supplementation on performance and training adaptations
Kreider, RB
Molecular and Cellular Biochemistry, 244(1): 89-94.

International Journal of Sports Medicine
Effects of oral creatine-pyruvate supplementation in cycling performance
Van Schuylemanbergh, R; Van Leemputte, M; Hespel, P
International Journal of Sports Medicine, 24(2): 144-150.

Journal of Physiology and Biochemistry
Creatine supplementation and performance in 6 consecutive 60 meter sprints
Javierre, C; Barbany, JR; Bonjorn, VM; Lizarraga, MA; Ventura, JL; Segura, R

Regulatory Toxicology and Pharmacology
Risk assessment for creatine monohydrate
Shao, A; Hathcock, JN
10.1016/j.yrtph.2006.05.005
CrossRef
Regulatory Toxicology and Pharmacology
Risk assessment for the amino acids taurine, L-glutamine and L-arginine
Shao, A; Hathcock, JN
Regulatory Toxicology and Pharmacology, 50(3): 376-399.
10.1016/j.yrtph.2008.01.004
CrossRef
Journal of Sports Science and Medicine
Short and longer-term effects of creatine supplementation on exercise induced muscle damage
Rosene, J; Matthews, T; Ryan, C; Belmore, K; Bergsten, A; Blaisdell, J; Gaylord, J; Love, R; Marrone, M; Ward, K; Wilson, E

Current Topics in Nutraceutical Research
CREATINE AND beta-ALANINE SUPPLEMENTATION IN STRENGTH/POWER ATHLETES
Hoffman, JR

Physician and Sportsmedicine
Oral creatine supplementation - Separating fact from hype
Juhn, MS

Journal of the American Dietetic Association
Oral creatine supplementation in male collegiate athletes: A survey of dosing habits and side effects
Juhn, MS; O'Kane, JW; Vinci, DM

Medical Hypotheses
Potential cytotoxic effect of chronic administration of creatine, a nutrition supplement to augment athletic performance
Yu, PH; Deng, Y
Medical Hypotheses, 54(5): 726-728.

International Journal of Sport Nutrition
No effect of heavy resistance training and creatine supplementation on blood lipids
Volek, JS; Duncan, ND; Mazzetti, SA; Putukian, M; Gomez, AL; Kraemer, WJ
International Journal of Sport Nutrition, 10(2): 144-156.

Journal of Sports Medicine and Physical Fitness
Creatine alpha-ketoglutarate is experimentally unproven - Response
Silber, ML

Journal of Applied Physiology
Effects of acute creatine monohydrate supplementation on leucine kinetics and mixed-muscle
protein synthesis
Parise, G; Mihic, S; MacLennan, D; Yarasheski, KE; Tarnopolsky, MA

Strength and Conditioning Journal
Creatine supplementation: Forms, function, and effects
Grande, BM

Journal of Strength and Conditioning Research
The effects of a 10-week, periodized, off-season resistance-training program and creatine supplementation among collegiate football players
Wilder, N; Gilders, R; Hagerman, F; Deivert, RG

Sports Medicine
Dairy products, meat and sports performance
Fogelholm, M

Nutrition
Effect of a 10-week strength training program and recovery drink on body composition, muscular strength and endurance, and anaerobic power and capacity
Chromiak, JA; Smedley, B; Carpenter, W; Brown, R; Koh, YS; Lamberth, JG; Joe, LA; Abadie, BR; Altorfer, G
10.1016/j.nut.2004.01.005
CrossRef
International Journal of Sport Nutrition and Exercise Metabolism
Effect of creatine and beta-alanine supplementation on performance and endocrine responses in strength/power athletes
Hoffman, J; Ratamess, N; Kang, J; Mangine, G; Faigenbaum, A; Stout, J

European Journal of Applied Physiology
Kinetics of creatine ingested as a food ingredient
Deldicque, L; Decombaz, J; Foncea, HZ; Vuichoud, J; Poortmans, JR; Francaux, M
European Journal of Applied Physiology, 102(2): 133-143.
10.1007/s00421-007-0558-9
CrossRef
Science & Sports
Ergonomic effects of creatine
Bigard, AX

Plos Clinical Trials
Creatine monohydrate and conjugated linoleic acid improve strength and body composition
following resistance exercise in older adults
Tarnopolsky, M; Zimmer, A; Paikin, J; Safdar, A; Aboud, A; Pearce, E; Roy, B; Doherty, T
Plos Clinical Trials, 2(): -. 10.1371/journal.pone.0000991
CrossRef
Agro Food Industry Hi-Tech
Creatine’s effects on thermoregulation: should we be concerned?
Rosene, JM
Agro Food Industry Hi-Tech, 18(5): -. 

Sports Medicine
Dietary supplements and the promotion of muscle growth with resistance exercise
Kreider, RB
Sports Medicine, 27(2): 97-110.

Science & Sports
Undesirable consequences of exogenous creatine supplementation: from fiction to reality
Poortmans, JR; Francaux, M

Annals of Neurology
Potential for creatine and other therapies targeting cellular energy dysfunction in neurological disorders
Tarnopolsky, MA; Beal, MF

Pharmacological Reviews
Clinical pharmacology of the dietary supplement creatine monohydrate
Persky, AM; Brazeau, GA

Journal of Sports Medicine and Physical Fitness
Scientific facts behind creatine monohydrate as sport nutrition supplement
Silber, ML

Medicine and Science in Sports and Exercise
Creatine supplementation and sprint performance in soccer players
Mujika, I; Padilla, S; Ibanez, J; Izquierdo, M; Gorostiaga, E

Nutrition Research
The effect of creatine monohydrate loading on maximal intermittent exercise and sport-specific strength in well trained power-lifters
Rossouw, F; Kruger, PE; Rossouw, J
Metabolism-Clinical and Experimental
Comparison of creatine ingestion and resistance training on energy expenditure and limb blood flow
Arciero, PJ; Hannibal, NS; Nindl, BC; Gentile, CL; Hamed, J; Vukovich, MD
Metabolism-Clinical and Experimental, 50(): 1429-1434.

Clinical Science
Effects of creatine loading and prolonged creatine supplementation on body composition, fuel selection, sprint and endurance performance in humans
van Loon, LJC; Oosterlaar, AM; Hartgens, F; Hesselink, MKC; Snow, RJ; Wagenmakers, AJM
Clinical Science, 104(2): 153-162.

Neurology
Creatine monohydrate enhances strength and body composition in Duchenne muscular dystrophy
Tarnopolsky, MA; Mahoney, DJ; Vajsar, J; Rodriguez, C; Doherty, TJ; Roy, BD; Biggar, D
Neurology, 62(): 1771-1777.

Acta Physiologica Hungarica
Creatine supplementation improves the anaerobic performance of elite junior fin swimmers
Juhasz, I; Gyore, I; Csende, Z; Racz, L; Tihanyi, J
10.1556/APhysiol.96.2009.3.6
CrossRef

Journal of Sports Science and Medicine
The effects of creatine long-term supplementation on muscle morphology and swimming performance in rats
Yildiz, A; Ozdemir, E; Gulturk, S; Erdal, S

Journal of Nutrition Health & Aging
Potential of Creatine Supplementation for Improving Aging Bone Health
Candow, DG; Chilibeck, PD

Journal of Nutrition Health & Aging
The Effects of Supplementation With Creatine and Protein on Muscle Strength Following A Traditional Resistance Training Program in Middle-Aged and Older Men
Bemben, MG; Witten, MS; Carter, JM; Eliot, KA; Knehans, AW; Bemben, DA

Journal of the International Society of Sports Nutrition
ISSN exercise & sport nutrition review: research & recommendations
Kreider, RB; Wilborn, CD; Taylor, L; Campbell, B; Almada, AL; Collins, R; Cooke, M; Earnest, CP; Greenwood, M; Kalman, DS; Kerksick, CM; Kleiner, SM; Leutholtz, B; Lopez, H; Lowery, LM; Mendel, R; Smith, A; Spano, M; Wildman, R; Willoughby, DS; Ziegenfuss, TN; Antonio, J
Journal of the International Society of Sports Nutrition, 7(): -. 
Journal of Sports Medicine and Physical Fitness
Acute creatine loading enhances human growth hormone secretion
Schedel, JM; Tanaka, H; Kiyonaga, A; Shindo, M; Schutz, Y

European Journal of Applied Physiology
Effect of creatine supplementation on metabolism and performance in humans during intermittent sprint cycling
Finn, JP; Ebert, TR; Withers, RT; Carey, MF; Mackay, M; Phillips, JW; Febbraio, MA

Deutsche Zeitschrift Fur Sportmedizin
Creatine in sports - an ergogenic supplement?
Nebel, R
Deutsche Zeitschrift Fur Sportmedizin, 53(): 213-220.

Military Medicine
Effect of creatine on performance of militarily relevant tasks and soldier health
Deuster, PA; Bennett, T; Bathalon, G; Armstrong, D; Martin, B; Coll, R; Beek, R; Barkdull, T; O'Brien, K; Deuster, PA
Military Medicine, 166(): 996-1002.

Cns Drugs
The role of creatine in the management of amyotrophic lateral sclerosis and other neurodegenerative disorders
Ellis, AC; Rosenfeld, J
Cns Drugs, 18(): 967-980.

Life Sciences
The effect of creatine supplementation on mass and performance of rat skeletal muscle
Young, RE; Young, JC
Life Sciences, 81(9): 710-716.
10.1016/j.lfs.2007.06.029
CrossRef
Pharmacological Research
Is there a rationale for the use of creatine either as nutritional supplementation or drug administration in humans participating in a sport?
Benzi, G
Journal of Athletic Training
Creatine supplementation and anterior compartment pressure during exercise in the heat in dehydrated men
Hile, AM; Anderson, JM; Fiala, KA; Stevenson, JH; Casa, DJ; Maresh, CM

Nutrition & Dietetics
Nutritional composition of red meat
Williams, P
Nutrition & Dietetics, 64(): S113-S119.
10.1111/j.1747-0080.2007.00197.x CrossRef

Physiological Genomics
Global and targeted gene expression and protein content in skeletal muscle of young men following short-term creatine monohydrate supplementation
Safdar, A; Yardley, NJ; Snow, R; Melov, S; Tarnopolsky, MA
Physiological Genomics, 32(2): 219-228.
10.1152/physiolgenomics.00157.2007 CrossRef

International Journal of Sport Nutrition and Exercise Metabolism
Conjugated Linoleic Acid Combined With Creatine Monohydrate and Whey Protein Supplementation During Strength Training
Cornish, SM; Candow, DG; Jantz, NT; Chilibeck, PD; Little, JP; Forbes, S; Abeysekara, S; Zello, GA

International Journal of Sports Medicine
Creatine loading does not impact on stroke performance in tennis
Eijnde, BO; Vergauwen, L; Hespel, P

International Journal of Sports Physiology and Performance
Side Effects of Creatine Supplementation in Athletes
Francaux, M; Poortmans, JR

International Journal of Sport Nutrition and Exercise Metabolism
The effects of creatine supplementation on cardiovascular, metabolic, and thermoregulatory responses during exercise in the heat in endurance-trained humans
Kilduff, LP; Georgiades, E; James, N; Minnion, RH; Mitchell, M; Kingsmore, D; Hadjicharlambous, M; Pitsiladis, YP

Journal of Sports Medicine and Physical Fitness
Effect of creatine on swimming velocity, body composition and hydrodynamic variables
Silva, AJ; Reis, VM; Guidetti, L; Alves, FB; Mota, P; Freitas, J; Baldari, C
Journal of the American College of Nutrition
Does creatine supplementation enhance athletic performance?
Cordain, L

Journal of Sports Medicine and Physical Fitness
Oral creatine supplementation improves multiple sprint performance in elite ice-hockey players
Jones, AM; Atter, T; Georg, KP

Medicine and Science in Sports and Exercise
Acute creatine loading increases fat-free mass, but does not affect blood pressure, plasma creatinine, or CK activity in men and women
Mihic, S; MacDonald, JR; McKenzie, S; Tarnopolsky, MA

Journal of Animal Science
Aerobic training, but not creatine supplementation, alters the gluteus medius muscle
D'Angelis, FHF; Ferraz, GC; Boleli, IC; Lacerda-Neto, JC; Queiroz-Neto, A

Nutrition
Impact of differing protein sources, and a creatine containing nutritional formula after 12 weeks of resistance training
Kerksick, CM; Rasmusse, C; Lancaster, S; Starks, M; Smith, P; Melton, C; Greenwood, M; Almada, A; Kreider, R
Nutrition, 23(9): 647-656.
10.1016/j.nut.2007.06.015
CrossRef

Strength and Conditioning Journal
Creatine supplementation
Haff, GG; Kirksey, KB

Sports Medicine
Adverse effects of creatine supplementation - Fact or fiction?
Poortmans, JR; Francaux, M
Sports Medicine, 30(3): 155-170.

Orthopedics
Thrombosis of the greater saphenous vein in a collegiate football place kicker
Robbe, R; Mair, S; Johnson, D; Madaleno, J
Greenwood, M; Kreider, RB; Greenwood, L; Byars, A

International Journal of Sport Nutrition
Effects of in-season (5 weeks) creatine and pyruvate supplementation on anaerobic performance and body composition in American football players
Stone, MH; Sanborn, K; Smith, LL; O'Bryant, HS; Hoke, T; Utter, AC; Johnson, RL; Boros, R; Hruby, J; Pierce, KC; Stone, ME; Garner, B

Acsm Health & Fitness Journal
Update: What we now know about creatine
Volek, JS

Creatine: From Basic Science To Clinical Application
Creatine in sports medicine: Nutritional supplementation and/or medicinal product?
Benzi, G
Creatine: From Basic Science To Clinical Application, 14(): 51-57.

Molecular and Cellular Biochemistry
Acute and moderate-term creatine monohydrate supplementation does not affect creatine transporter mRNA or protein content in either young or elderly humans
Tarnopolsky, M; Parise, G; Fu, MH; Brose, A; Parshad, A; Speer, O; Wallimann, T
Molecular and Cellular Biochemistry, 244(1): 159-166.

Journal of Athletic Training
Creatine supplementation increases total body water without altering fluid distribution
Powers, ME; Arnold, BL; Weltman, AL; Perrin, DH; Mistry, D; Kahler, DM; Kraemer, W; Volek, J

European Journal of Applied Physiology
The effects of creatine supplementation on muscular performance and body composition responses to short-term resistance training overreaching
Volek, JS; Ratamess, NA; Rubin, MR; Gomez, AL; French, DN; McGuigan, MM; Scheett, TP; Sharman, MJ; Hakkinen, K; Kraemer, WJ
10.1007/s00421-003-1031-z
CrossRef

Science & Sports
Creatine supplementation - A review of the literature
Saint-Pierre, MA; Poortmans, J; Leger, L
UNSP S0765-1597(02)00118-1/REV
CrossRef
Journal of Sports Medicine and Physical Fitness
Screening blood tests in members of the Israeli National Olympic team
Eliakim, A; Nemet, D; Constantini, N

International Journal of Sport Nutrition and Exercise Metabolism
Short-term creatine supplementation improves maximum quadriceps contraction in women
Kambis, KW; Pizzedaz, SK

Metabolism-Clinical and Experimental
Magnesium-creatine supplementation effects on body water
Brilla, LR; Giroux, MS; Taylor, A; Knutzen, KM
Metabolism-Clinical and Experimental, 52(9): 1136-1140.
10.1016/S0026-0495(03)00188-4 CrossRef

Medicine and Science in Sports and Exercise
Effect of creatine and weight training on muscle creatine and performance in vegetarians
Burke, DG; Chilibeck, PD; Parise, G; Candow, DG; Mahoney, D; Tarnopolsky, M
10.1249/01.MSS.0000093614.17517.90 CrossRef

Physician and Sportsmedicine
Creatine supplements face scrutiny - Will users pay later?
Schnirring, L

Journal of Sports Science and Medicine
Exercise performance and muscle contractile properties after creatine monohydrate supplementation in aerobic-anaerobic training rats
Boyadjiev, N; Popov, D; Delchev, S

Strength and Conditioning Journal
Supplements for Strength-Power Athletes
Campbell, BI; Wilborn, CD; La Bounty, PM
10.1519/SSC.0b013e3181c212b9 CrossRef

Critical Reviews in Food Science and Nutrition
Nutritional supplements to increase muscle mass
Clarkson, PM; Rawson, ES

Pediatrics
Creatine use among young athletes
Metzl, JD; Small, E; Levine, SR; Gershel, JC

Journal of Pharmaceutical Sciences
Evaluation of creatine transport using Caco-2 monolayers as an in vitro model for intestinal absorption
Dash, AK; Miller, DW; Huai-Yan, H; Carnazzo, J; Stout, JR
Journal of Pharmaceutical Sciences, 90(): 1593-1598.

Journal of Applied Animal Research
A review of creatine supplementation and its potential to improve pork quality
James, BW; Goodband, RD; Unruh, JA; Tokach, MD; Nelssen, JL; Dritz, SS

Medicine & Science in Sports & Exercise
Effects of oral creatine supplementation on muscular strength and body composition
BECQUE, MD; LOCHMANN, JD; MELROSE, DR

Medicine & Science in Sports & Exercise
Effect of creatine loading on long-term sprint exercise performance and metabolism
PREEN, D; DAWSON, B; GOODMAN, C; LAWRENCE, S; BEILBY, J; CHING, S

Current Opinion in Clinical Nutrition & Metabolic Care
Can the use of creatine supplementation attenuate muscle loss in cachexia and wasting?
Sakkas, GK; Schambelan, M; Mulligan, K
Current Opinion in Clinical Nutrition & Metabolic Care, 12(6): 623-627. 10.1097/MCO.0b013e328331de63

The Journal of Strength & Conditioning Research
Effect of a Pre-Exercise Energy Supplement on the Acute Hormonal Response to Resistance Exercise
Hoffman, JR; Ratamess, NA; Ross, R; Shanklin, M; Kang, J; Faigenbaum, AD
The Journal of Strength & Conditioning Research, 22(3): 874-882. 10.1519/JSC.0b013e31816d5db6

The Effects of 8 Weeks of Creatine Monohydrate and Glutamine Supplementation on Body
Composition and Performance Measures
LEHMKUHL, M; MALONE, M; JUSTICE, B; TRONE, G; PISTILLI, ED; VINCI, D; HAFF, EE; KILGORE, JL; HAFF, GG

PDF (422)
The Journal of Strength & Conditioning Research
Swim Performance Following Creatine Supplementation in Division III Athletes
SELSBY, JT; BECKETT, KD; KERN, M; DEVOR, ST

PDF (194)
The Journal of Strength & Conditioning Research
The Effects of Creatine Loading on Thermoregulation and Intermittent Sprint Exercise Performance in A Hot Humid Environment
WRIGHT, GA; GRANDJEAN, PW; PASCOE, DD

PDF (169)
Clinical Journal of Sport Medicine
Nutritional Consideration in the Aging Athlete
Tarnopolsky, MA
Clinical Journal of Sport Medicine, 18(6): 531-538.
10.1097/JSM.0b013e318187ac44
PDF (95) | CrossRef
The Journal of Strength & Conditioning Research
Effect of Recovery Interval on Multiple-Bout Sprint Cycling Performance After Acute Creatine Supplementation
COTTRELL, GT; COAST, JR; HERB, RA

PDF (261)
The Journal of Strength & Conditioning Research
The Effects of Protein and Amino Acid Supplementation on Performance and Training Adaptations During Ten Weeks of Resistance Training
KERKSICK, CM; RASMUSSEN, CJ; LANCASTER, SL; MAGU, B; SMITH, P; MELTON, C; GREENWOOD, M; ALMADA, AL; EARNEST, CP; KREIDER, RB

PDF (174)
The Journal of Strength & Conditioning Research
Effects of Creatine Supplementation and Resistance Training on Muscle Strength and Weightlifting Performance
RAWSON, ES; VOLEK, JS
Clinical Journal of Sport Medicine

**Creatine Supplementation Patterns and Perceived Effects in Select Division I Collegiate Athletes**
Greenwood, M; Farris, J; Kreider, R; Greenwood, L; Byars, A
Clinical Journal of Sport Medicine, 10(3): 191-194.

Clinical Journal of Sport Medicine

**Oral Creatine Supplementation and Athletic Performance: A Critical Review**
Juhn, MS; Tarnopolsky, M
Clinical Journal of Sport Medicine, 8(4): 286-297.

The Journal of Strength & Conditioning Research

**Effects of Ribose Supplementation on Repeated Sprint Performance in Men**
BERARDI, JM; ZIEGENFUSS, TN

Medicine & Science in Sports & Exercise

**Short-term creatine supplementation does not alter the hormonal response to resistance training**
OP 'T EIJINDE, B; HESPEL, P

Medicine & Science in Sports & Exercise

**Effects of creatine supplementation on muscle power, endurance, and sprint performance**
IZQUIERDO, M; IBANEZ, J; GONZÁLEZ-BADILLO, JJ; GOROSTIAGA, EM

The Journal of Strength & Conditioning Research

**Effects of Four Weeks of High-Intensity Interval Training and Creatine Supplementation on Critical Power and Anaerobic Working Capacity in College-Aged Men**
Kendall, KL; Smith, AE; Graef, JL; Fukuda, DH; Moon, JR; Beck, TW; Cramer, JT; Stout, JR
10.1519/JSC.0b013e3181b1fd1f

Medicine & Science in Sports & Exercise

**Effects of Whey Isolate, Creatine, and Resistance Training on Muscle Hypertrophy**
CRIBB, PJ; WILLIAMS, AD; STATHIS, CG; CAREY, MF; HAYES, A
10.1249/01.mss.0000247002.32589.ef
Creatine Supplementation and Its Effect on Musculotendinous Stiffness and Performance

WATSFORD, ML; MURPHY, AJ; SPINKS, WL; WALSHE, AD

PDF (216)

The Effects of Creatine Monohydrate Supplementation With and Without D-Pinitol on Resistance Training Adaptations

Kerksick, CM; Wilborn, CD; Campbell, WI; Harvey, TM; Marcello, BM; Roberts, MD; Parker, AG; Byars, AG; Greenwood, LD; Almada, AL; Kreider, RB; Greenwood, M
The Journal of Strength & Conditioning Research, 23(9): 2673-2682.
10.1519/JSC.0b013e3181b3e0de
PDF (148) | CrossRef

Voluntary Muscle Function after Creatine Supplementation in Acute Hypobaric Hypoxia

BAKER-FULCO, CJ; FULCO, CS; KELLOGG, MD; GLICKMAN, E; YOUNG, AJ
Medicine & Science in Sports & Exercise, 38(8): 1418-1424.
10.1249/01.mss.0000228948.70399.38
PDF (269) | CrossRef

A Creatine-Protein-Carbohydrate Supplement Enhances Responses to Resistance Training

CRIBB, PJ; WILLIAMS, AD; HAYES, A
10.1249/mss.0b013e31b4f52a
PDF (278) | CrossRef

Is Running Performance Enhanced With Creatine Serum Ingestion?

ASTORINO, TA; MARROCCO, AC; GROSS, SM; JOHNSON, DL; BRAZIL, CM; ICENHOWER, ME; KNEESSI, RJ

PDF (116)

Re: Long-Term Oral Creatine Supplementation Does Not Impair Renal Function in Healthy Athletes

Kuehl, K
Medicine & Science in Sports & Exercise, 32(1): 248.
Physiological and Health Effects of Oral Creatine Supplementation

Effects of Creatine Supplementation on Body Composition and Renal Function in Rats

Effects of Acute Creatine Supplementation on Multiple Sprint Cycling and Running Performance in Rugby Players

Potential Side Effects of Oral Creatine Supplementation: A Critical Review

The Neurosurgeon in Sport: Awareness of the Risks of Heatstroke and Dietary Supplements

Effect of Creatine Supplementation During Cast-Induced Immobilization on the Preservation of Muscle Mass, Strength, and Endurance
EFFECTS OF SIX WEEKS OF [beta]-HYDROXY-[beta]-METHYLBUTYRATE (HMB) AND HMB/CREATINE SUPPLEMENTATION ON STRENGTH, POWER, AND ANTHROPOMETRY OF HIGHLY TRAINED ATHLETES

O'CONNOR, DM; CROWE, MJ